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TROPICAL HURRICANES.

BY

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The Caribs, who dwelt in the West India Islands long ago, before the coming of the white man, had a word in their tongue which has come down to us and passed into many languages. It is "Hurakan." In the China Seas they speak of a "Typhoon." The Samoans have their own word for it, and so on through every tropical country. These words all mean in the original a mighty wind, and refer to the same phenomena.

Now that we have possessions in the West Indies our attention has been called especially to that peculiar and complicated storm known as the tropical cyclone. For the first time American soil has been swept by its full fury, and our weather observers who have during the past year been distributed around the Caribbean Sea have had an opportunity of chronicling, if not the most severe, yet probably one of the most destructive storms that has ever visited these regions. During the past 300 years, 355 such hurricanes have been recorded; but these were only those of exceptional severity. It is as mathematically certain as the laws which govern them that they will continue to recur on an average of several every year, as long as the West Indies exist. It is interesting to conjecture here what would have been the result had Columbus encountered one of these storms on his first voyage of discovery. Had he passed through the "eye" of a severe hurricane it is extremely doubtful if his frail caravels could have weathered it, and the discovery of the new continent must have been delayed many years.

The hurricane of August 7, 8, 9, 1899, was like all others, differing only in degree. The author was on the southern coast of Santo Domingo at the time. Early on the morning of the 7th, long, heavy swells began coming in from the eastward, which was the method the storm used to telegraph its approach.

As these long ocean waves may travel with a velocity of 80 or even 100 miles an hour, while the storm itself seldom travels more than 20 miles an hour, it will be seen that its arrival may be anticipated a day or more in advance. In the afternoon of the 7th a telegram was received from Washington, saying that a hurricane

somewhere to the eastward of Dominica was approaching that island in a westerly and somewhat northerly direction. If there had been any doubt as to the meaning of the long swells coming from the eastward all was now clear. The probable course of events could be forecast as follows—not from any special knowledge regarding cyclones (for our knowledge as to their laws has been hitherto singularly deficient), but because year after year they carry out the same programme, almost without variation. The wind would blow from the eastward of north, through north to southwest; the barometer would progressively fall, afterwards rising to about its original level. The track of the storm would be to the westward and northward. It would pass over Porto Rico by Turk's Island, sweep the Bahamas, and recurving somewhere about latitude 30° , would roll up the coast of the United States and out to sea, and then finally be dissipated. In the wake of the "Freight Train" the afterswirl would follow, and a persistent southeast wind could be expected. Martinique, Guadeloupe, St. Thomas, Montserrat, Porto Rico, Santo Domingo and the Bahamas, would be likely to suffer more or less damage according to the severity of the cyclone. And we know now that all this is what practically took place.

What the battering-ram effect of wind striking with a velocity of 80, 100, 125, or even 150 miles an hour is, and what the inundating effect is of the tremendous precipitation caused by cyclones, and of the tidal waves which the low centre may carry along, we have lately seen, and have seen many times in the past. The hurricane of October, 1780, called the Great Hurricane, was very similar to the recent one in many respects. While the loss of life in Porto Rico was appalling, it cannot be compared to the loss caused by the cyclone at Barisal and Backergunge, in India, in June, 1822, when more than 50,000 lives and a vast amount of property was destroyed. The West India hurricane of August, 1873, killed more than 500 people, damaged, stranded or wrecked more than 1,000 vessels, besides doing an enormous amount of damage to buildings on shore. Such is the terrible and extraordinary interest these phenomena possess for us.

It will be interesting to attempt to trace the course of a hurricane from its birth to its end. It must be premised that the sun, in its course round the earth day after day, heats a broad zone of the atmosphere directly under it. The air, becoming rarified by this excessive heat, rises directly upwards, very much like the hot air in a flue. This zone is known as the doldrums, and is about 10° wide. From the north and the south surface currents of cold

air rush in to fill this void, which, owing to the revolutions of the earth from west to east, gives a northeasterly direction to the wind coming from the north and a southwesterly direction to the wind coming from the south. When the sun is to the south of the Equator, a corresponding state of affairs exists, the doldrums being bordered by the southeast trades on the south and by the northeast trades on the north, which become northwesterly after crossing the Equator. These so-called trade-winds, with the interlying zone of doldrums, follow the sun north and south of the Equator. A tropical cyclone always originates in the doldrums, and it may start over land or sea. If the surface of the earth were covered with water alone, it would be difficult to see how a hurricane could arise, since, the conditions being uniform everywhere, there would be no determining point from which it could take its origin. With land scattered about it is a different matter. Since the specific heat of water is much greater than that of land, the heat pouring down from the sun raises the underlying islands to a much greater temperature than the surrounding water during the day, and since during the night the land cools more rapidly, we have generally a "low" over an island during the day and a "high" during the night, which give rise to the sea-breeze of the day and the land-breeze of the night, so well known in the tropics. It is easy to see how a "low," arising over a sufficiently large island, could give rise to a very respectable cyclone.

Where, as in the recent cyclone, the "low" originated on the sea (to the eastward of Dominica), it is possible that a cause lay in the great ocean current coming up along the coast of South America, or a heavy precipitation of rain at this point freeing a vast amount of latent heat, and, by relieving the atmosphere of the pressure of a large amount of aqueous vapor, causing a diminution in the pressure that started the phenomenon. It seems hardly necessary to speculate further on how "lows" of unusual dimensions may be formed—on the contrary, it seems wonderful that they are not formed oftener.

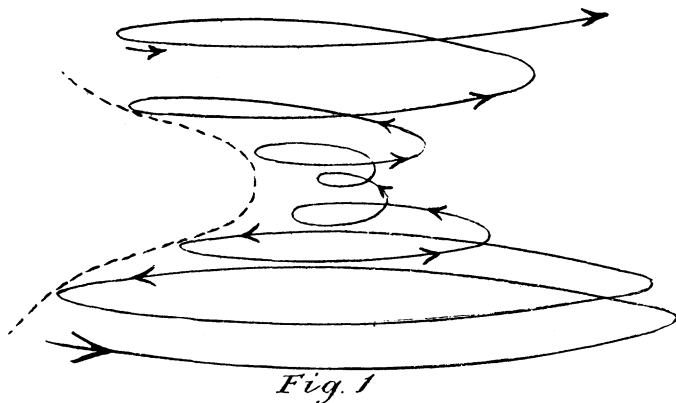
However that may be, we will simply suppose that a barometrical depression of unusual proportions occurs suddenly at some point. The wind from all surrounding points immediately begins to rush towards the vortex. Since the air in the doldrums is usually calm, it must have the same revolutionary velocity as the part of the earth over which it lies. Consequently, all the air coming from the southward will be deflected to the eastward of the centre, and all the air coming from the northward will be deflected to the west-

ward, and a whirlwind will be formed which must revolve contra-clockwise. It will easily be seen that this is a general law for the northern hemisphere, viz., that every "low" in the northern hemisphere must result in a contra-clockwise vortex, while every "low" in the southern hemisphere must cause a clockwise vortex. Conversely, every "high" in the northern hemisphere must cause a clockwise whirl, while the opposite is true for the southern hemisphere.

We have, then, a phenomenon the counterpart of which is seen in the water flowing out of the drain-pipe of a bath-tub; or, more exactly, in the whirl of leaves on a gusty autumn day; or in a water-spout, which is a miniature cyclone.

Our cyclone is now formed. Before it starts off on its journey, let us survey it carefully.

The diameter of a cyclone may be anywhere from 100 to 1,000 miles, and its height from 20 to 40 miles. As the air is drawn in by a central attracting force, it follows approximately the so-called laws of Equal Areas, viz., a line connecting a given mass of air with the centre will describe equal areas in equal times. The general form of the whirl is as shown in Figs. 1, 2 and 3, Fig. 1 being a vertical view, and Figs. 2 and 3 being horizontal projections.



It will be seen that a portion of air moving with comparative slowness at first, as it falls into the outer edge will gradually increase in velocity until it reaches the narrowest part of the "hour glass," which is some distance above the surface of the earth.

The highest surface velocities are not far from the axis and are usually 80 to 100 miles an hour—a force which few objects can withstand. It will be seen from Fig. 1 that "axis of the storm" is

a more correct term than "storm centre." The barometrical pressure across such a cyclone can be well seen by examining the accompanying pressure gradient. It will be noticed that we have come to speak of our cyclone as an entity by itself, totally different from the surrounding air. Since its parts preserve their distances and relative relations it may, for all intents and purposes, be regarded as a solid body of equal mass rotating with its average velocity. This does not mean that the same air always constitutes the same cyclone, for such is not the case. The identical particles of air that

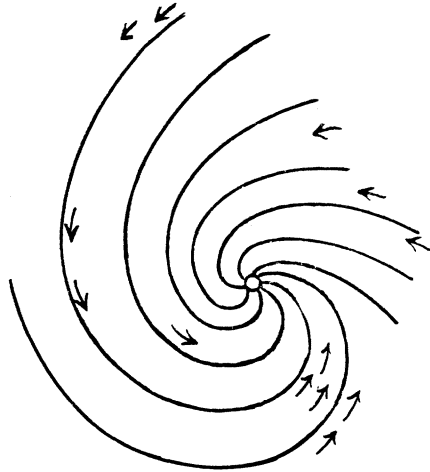


Fig. 2

caused so much change in Porto Rico are not transported to the Bahamas to continue their work there. On the contrary, this air, after having been "through the mill," is left high above the earth not far from where it was originally derived. It is like a rotary snow-plough, where, though the mass in rotation is constantly changing, still an average energy of rotation is preserved.

The most important question of all from every point of view, both practical and theoretical, now awaits us, viz. : Why does the cyclone move and what are the laws governing this motion? Up to this time this part of the problem has been considered inexplicable.

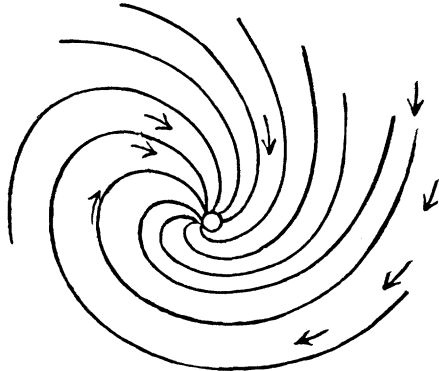
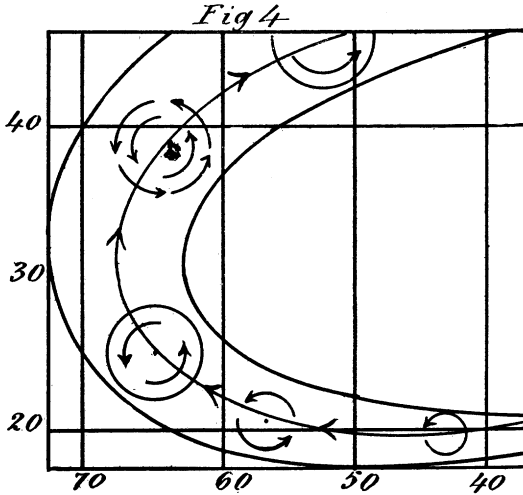


Fig. 3

It will be seen that if the laws governing revolving storms (and all storms are revolving) were understood, and this knowledge could be applied to predicting their paths, meteorology would advance with one bound from scientific guesswork to an exact science. If the path of a cyclone can be pre-

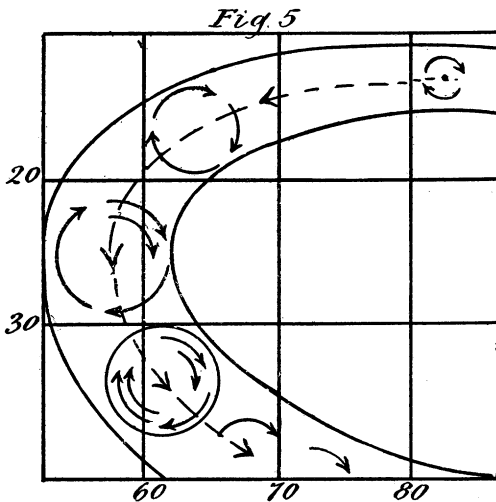
dicted from its "elements" with the same accuracy as the path of a comet, then the science of meteorology acquires a dignity com-



mensurate with that of astronomy. I believe this point has been reached. Given a cyclone with a known "moment of inertia," of a known mass, rotating with a mean angular velocity at a given latitude and longitude, and its path and subsequent motion may be determined. The importance of this knowledge to all re-

gions lying in the track of the cyclone is evident.

Let Fig. 6 represent a section of the earth through its axis and C a cyclone at the extremity of the radius OC rotating in the north-



ern hemisphere contra-clockwise. Since the radius OC rotates with the angular velocity of the earth, our cyclone may be regarded as an ordinary gyroscope. As the average velocity of the air of which the cyclone is formed is that of the surface of the earth under its axis, we may consider merely the motion of a gyroscope OC moving about a fixed point O or an imponderable axis OC.

It is not the intention of the author to give the complete analysis of the motions of a gyroscope under the given conditions, since this

is professedly a popular article. The object is simply to elucidate the subject to the non-mathematical mind.

To the reader with a slight knowledge of mathematics, it will be sufficient to say that the gyroscope is an instrument that develops a deflective force normal to the plane in which it is turned. For instance, if our cyclone is turned with the earth, it will develop a deflective force, tending to increase its latitude, and a certain velocity will be developed towards the pole.

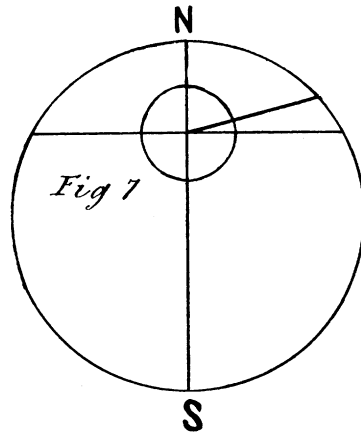
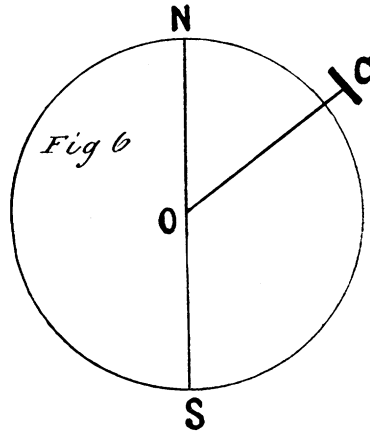
This velocity likewise will develop a deflective force, tending to increase its longitude.

Let x represent the longitude and y the latitude of the axis, and suppose an initial impulsive velocity equal to the velocity of the earth at the point be given to the cyclone. Considering only a portion of the spherical surface small enough to be regarded as plane, we have as the equations of motion:

$$\left(\frac{d^2y}{dt^2} = k \frac{dx}{dt} \text{ \& \; } - \frac{d^2x}{dt^2} = K \frac{dy}{dt} \right)$$

since the normal deflecting force is proportional to the angular velocity. Integrating these equations we get as the curve of motion $x^2 + y^2 - 2 \frac{V_0}{k} y = 0$, which is the equation of a hyperbola situated vertically, with the origin at the upper vertex. It may be remarked that k above is equal to $\frac{CW}{RM}$ where R is a radius of the earth, and C , W and M are respectively the Moment of Inertia about the axis, the angular velocity and the mass of the cyclone.

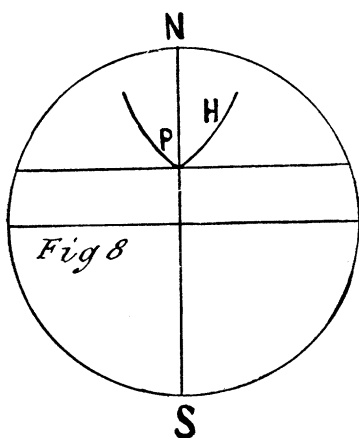
It will be seen, therefore, that if the earth were at rest, and the cyclone given an initial velocity equal to its actual rotational veloc-



ity and started from a point P, it would describe the curve PH, which is for a small surface a hyperbola, as drawn in the figure with P the initial point at the vertex. Since no work is done the living forces must remain constant. Therefore

$$\left(\frac{dx}{dt}\right)^2 \sin^2 \vartheta + \left(\frac{d\vartheta}{dt}\right)^2 = \text{Const.}$$

In other words, the gyroscope or cyclone will travel in the curve with a constant velocity equal to that originally impressed upon it. To obtain the actual path of the cyclone, we must compound the above motion with the motion of the earth about the axis. It is readily seen that the cyclone, starting out with the same velocity as the point of the earth on which it rests, gradually lags



behind and goes to the northward. As it moves in the right-hand branch of the hyperbola PH it finally reaches a point where its velocity is equal to that of the earth. Here it stops going to the westward; shortly beyond its velocity becomes greater than that of the earth, owing to the diminishing circles of latitude. Here it moves to the eastward, but during the whole of its motion continually makes northing. The arm of the hyperbola being regarded as a straight line, which it may nearly

be, it will be seen that the velocity to the northward is tolerably constant, while the velocity to the westward is constantly retarded and that to the eastward constantly accelerated; so the curve of the cyclone on the earth's surface must closely resemble a parabola, with the axis east and west. It is well known that a body moving with a constant velocity in one direction and with a constantly accelerated or retarded velocity in a direction at right angles must describe a parabola—a projectile, for instance. And such, in fact, do we find to be the actual paths taken by cyclones. The above is a rigidly exact explanation of the path of a cyclone, which has been a sore puzzle ever since it was first observed. Compare the paths delineated in Chart 1 and 11 from Piddington's *Sailor's Hornbook*. It will be seen that these paraboloid curves all have individual differences, depending upon differences in C, W and M, and the latitude and longitude where they started. That the path

can easily be calculated from the "elements" is now clear. The meridian where it will recurve, its velocity at any point, and in fact anything about its subsequent motion can be predetermined. As to its velocity, it will be seen that if the generating hyperbola is very broad, so that the branches tend to coincide with the parallel of latitude on which it rests, the velocity may be very slow, but it never can be stationary. Some authors have spoken of stationary cyclones. Mathematical analysis shows that such a thing is impossible. When the branches are very narrow there may be a high velocity. As a matter of fact the observed velocities have ranged from 3 to 50 miles an hour or even more.

It remains to explain the observed broadening out of cyclones as they progress. This is on the same principle as a snowball increases in size by rolling. They are rolling stones that gather moss. The tendency of this is to destroy the original motion of rotation and lead to their dissipation. This is further helped along by friction on the surrounding air and on the surface of the earth. The continual precipitation of rain leads to the escape of a constant supply of latent heat, which acts in the axis like a flue and has a continual "winding-up effect." How far these antagonistic forces balance each other it is impossible to say. They frequently have energy enough to keep under way for two weeks or more, though many die out in a week and the feeble ones in a few days.

Much condensation is a concomitant of most cyclones, as might be expected when saturated vapors are exposed to various temperatures and pressures. In a waterspout the hot saturated air of the central shaft is surrounded by the cold spiral of the external air, and condensation results; but the water here is wholly fresh. There is no sucking up of the sea water, appearances notwithstanding.

These tropical cyclones, as has been said before, are not limited to the West Indies, but are found in the doldrums everywhere especially where there is a mixture of land and water. The author has been in four of these storms—three in the West Indies and one at Apia, Samoa. Two of these were axial. The subjective and objective symptoms are the same in all. The last sunset before the storm has a peculiar look, which can best be described as "oily." There is no mistaking such a sunset when once seen before. These storms last three days, as a rule, at the same point. The circumference is cloud-capped, but the axis is usually clear. An absolute calm exists in the axis, which lasts only for a short time (one hour or more). Here are found mountainous, confused seas, which are very dangerous—more dangerous, in fact, than the winds.

When coming upon indications of an approaching cyclone at sea, the navigator can usually, from the direction of the wind, determine his position relatively to the path of the storm, and lay his course so as to escape as much of it as possible. Since the axis travels at little more than steamship speed on an average, he will usually be successful.

On land these storms cannot be avoided, and should be met by prudent anticipation. Areas of land that have been inundated and are liable to be inundated again should not be built upon. But human nature is much the same, whether in the United States or Porto Rico. When a hurricane revisits any place it usually finds the same work to do over again.

In recapitulating it will be seen that when the "elements" of a storm have suitable values, it may never recur, though this is almost always the case. A cyclone has never been known to cross the Equator; the above analysis shows that such a result is impossible. The above laws apply to any storm at any point of the earth's surface. The only difference between a tropical cyclone and other atmospheric disturbances lies simply in the superior energy of the former; and the energy of all is seen to be derived directly from the sun.

In summing up, we see that a "low" is formed by the sun at some point determined by local conditions. Owing to the rotation of the earth on its axis, a whirlwind must result contra-clockwise in the northern hemisphere and clockwise in the southern hemisphere. The energy of the whirlwind will be proportional to the difference of temperature of its parts, as is the case in all heat engines—and a cyclone may be regarded as a heat engine. A cyclone having its own proper rotational velocity, combined with a rotation about the axis of the earth, is a gyroscope simply, and obeys all gyroscopic laws.

It has long been a source of wonderment that the cyclone should move, just as for years it was considered a paradox that when acted upon by gravity the gyroscope should sustain itself and not fall to the ground. Some idea of the force impelling it may be formed by considering the cyclone as a solid wheel revolving about its axis. If all the axles in the world were welded together into one, it would be unable to hold the cyclone to a fixed point.

The independent motion of a gyroscope, acting under the two rotational forces described above, is in a hyperboloid curve, *i. e.*, it is as close an approach to an hyperbola as it is possible to describe

on a spherical surface. We may call this curve a "Spherical Hyperboloid."

This independent motion of its own, combined with the revolution of the earth on its axis, gives us the path of the cyclone as traced on the surface of the earth. This path resembles a parabola with its vertex pointing to the west. According to the conditions of the problem, the axis of the spherical paraboloid may deviate somewhat to the northward (or southward) of a strictly east and west line. The detailed analysis of the problem, together with the computation formulæ, would be out of place in any other than a mathematical journal.